Statistics Canada | Statistique Canada

Science and Technology Statistics Division

Division de la statistique des sciences et de la technologie

Canada

THE MEASUREMENT OF INDUSTRIAL INNOVATION

H. Stead
Science, Technology and
Capital Stock Division,
March, 1985

Table of Contents

Introduction to innovation

Innovation and policy
- Introduction
- The effects of innovation
- The climate for innovation
- The current activity in innovation

Innovation and statistics
- Introduction
- The climate for innovation
- Detecting and counting innovations
- The effects of innovation

Conclusion

Appendix

Introduction to Innovation

This note is written to assist the development of appropriate innovation indicators for science policy. It is not a research paper on innovation nor a text on the subject. It ignores, either deliberately or because of the author's ignorance, most of the literature on innovation as an economic phenomenon. It is intended to help statisticians and science policy advisors to conceptualize, develop and refine indicators.

An **indicator** is a measure selected for elucidating a particular concept.(1) For example, the number of scientists in a discipline in a country is a measure. This number might be considered one indicator of the stock of knowledge in that discipline in the country. The use of indicators is illustrated by the following quotation:

> "These quantitative measures aim to provide a broad base of information to assist the planning, debate, and negotiation which surround the specific issues faced by policy-makers. They are not intended to replace the judgement of such decisionmakers, but to inform them. ... When considered as multiple indicators of a phenomenon, these data and analyses present a more comprehensive picture and encourage broader perspectives. As is true of all indicators, they illuminate by providing indirect reflections of status, behaviour, or performance." (2)

An innovation is a new or significantly improved saleable product or an operational process in industry and commerce. The **activity of innovation** consists of the transformation of an idea into the product or process. It includes whatever scientific, technical, commercial or financial steps necessary for the successful development and marketing of new or improved products, processes and equipment.

The definition of industrial innovation referred to a product or a process, and this dichotomy is necessary to the analysis and measurement of innovation. The distinction is not, of course, always apparent in the real world: one company's process generally uses other companies' products. The development of the financial system illustrates the interplay between product and process innovations. Innovations such as the telegraph and the undersea cable, the computer and the automatic teller have resulted in innovations in the processes of transferring and managing money.

It should, however, be possible to classify any innovation as at least primarily product or primarily process at the time and at the stage of our observation. The difference is less significant when we are considering indicators of the potential for innovation but is crucial when looking at innovation as a contributor to productivity increases. Some examples of innovations, both product and process, are given below to illustrate our concept of innovation.

The variable pitch propellor (product)

Invented and patented by a private inventor (W.R. Turnbull of New Brunswick) in the 1920s and commercially produced by a number of companies, particularly Curtiss Wright. The innovation permits the pitch or length of a propellor to be changed to the most efficient position for a airplane's speed or activity. (3)

The self-propelled combine (product)

This is a product which embodies a process or series of processes. One person operates the combine which moves through the wheatfield cutting, threshing, cleaning and delivering the grain. It was invented by Thomas Carroll at Massey-Harris in the late 1930s. (3)

The air curtain for submarine blasting (process)

In order to protect people or things from the effects of underwater blasts, a curtain of air bubbles is produced from pipes laid below the blast site to absorb the shock waves. The technique was patented by Adolphe Laprairie of Canadian Industries Limited and first used in 1954. (3)

The flotation process for separating minerals (process)

In order to separate the minerals, such as lead and zinc, which are found in the mixed ores of the Kootenay region, the froth flotation process was developed by COMINCO in the early 1920s. (3)

Innovations which have been studied in depth include:

- the heart pacemaker
- hybrid grains
- electrophotography
- input-output economic analysis
- organophosphorus insecticides
- oral contraceptives
- magnetic ferrites
- the video tape recorder (4)

From a brief contemplation of this short list it is apparent that innovation is a fundamental part of our lives. For example, millions or hundreds of millions are alive today because of hybrid grains and organophosphorus insecticides; millions are not alive today because of oral contraceptives. It also illustrates how rapidly innovations can become absorbed into the technological and social fabric of society.

Innovations are man-created phenomena which are intended to lead to change. Process innovations can lead to the extraction, refinement or production of better/different substances and products, or to the lower-cost extraction, refinement or production of the same substances and products. The table

below, based on work by Enos (5) as described by Freeman (6), illustrates the effects of process innovations on production inputs.

TABLE. Comparison of Two Gasoline Refining Processes

Production inputs	Inputs per 100 gallons of gasoline produced		Savings
	Burton process c. 1913	Fluid catalytic cracking c. 1955	%
Raw materials (gals)	396.0	170.0	57
Capital (1939 $)	3.60	0.52	86
Labour (person-hours)	1.61	0.02	99
Energy (millions of BTUs)	8.4	1.1	87

Source: The Economics of Industrial Innovation, C. Freeman, Frances Pinter Ltd., London, 1982, p. 27.

Product innovations are new or improved products which may, if used in industrial production or to provide some commercial service, result in improved productivity in the user industry. Examples from the innovations identified earlier include the self-propelled combine, hybrid grains and organophosphorus insecticides, all of which increased agricultural productivity. Today, robots and various computer-linked machines are being used to improve productivity in more and more manufacturing processes.

Product innovations can also result in the creation of new industries. Innovations in steam machinery, steam locomotion, rail construction, switching devices, etc., permitted the development of the railroad industry. Then sufficient innovations came together to enable the automobile industry to evolve. And so on, for whatever industry we care to name.

It is also appropriate, now that we are trying to paint a very broad picture of the phenomenon of innovation, to remem-

ber that the creation and development of almost any industry results in social and economic innovations. The railroad and the development of underpopulated land or the railroad and international trade and war, for example. The automobile and the homogenization of societies through the mobility of individuals is another example.

Technological innovation has also a major role in some theories of economic growth. Schumpeter (7) argued that innovation was a cause of economic growth and especially of its cyclical nature. This theory was overshadowed by those of Keynes and other post World War II economists but is now being reconsidered. (8) The following lengthy quotation from Christopher Freeman summarizes his thinking about innovation and economic growth and suggests that technology policy may lead to the solution or mitigation of the current economic malaise.

"Throughout this book it has been maintained that the emergence of new technologies and their assimilation in the economies of industrial countries, which is an extremely important aspect of long-term economic development, is not a smooth continuous process. Specifically, it has been argued that technical change is extremely uneven over time; as between industries and broad sectors of the economy; and geographically as between regions and countries. The diffusion of clusters of technical innovations of wide adaptability is capable of imparting a substantial upthrust to the growth of the economic system, creating many new opportunities for investment and employment and generating widespread secondary demands for goods and services. Over time, however, these new 'technological systems' mature and their investment and employment consequences tend to change. The 'compensation effects', which might mitigate these tendencies, operate only imperfectly and often with long delays. Much of the stock of capital equipment already in existence in manufacturing may be rather inflexible in terms of its employment potential ... and new vintages of equipment may require heavy investment.

The promotion of major new technological systems and of productivity growth based on technical change may be an important means to help restore the economic health of the mature industrialized countries. This conclusion emerges from the earlier experiences of recovery from depression as well as from the more recent Japanese experience. Particu-

larly important would be innovations of wide adaptability, which could lead to a combination of high productivity gains and greatly improved profitability." (9)

Grossly simplified, the association of industrial innovation with long waves is the following: a great swell in economic activity is generated by a cluster of major and minor innovations and the subsequent growth of firms and new industries. These innovations would tend to be for products and systems. The innovations are diffused, technical advance becomes harder and more expensive, profits are reduced through increased competition and new innovations tend to be related to processes, largely to cut costs to meet the increased competition. Economic and innovative activity declines until a new burst of innovation occurs.

Definitions

Industrial Innovation

An industrial innovation is a new or significantly improved saleable product or an operational process in industry and commerce. It is something which did not exist before in its present form and it is something which works or which is a commercial success. The adjective "industrial" is used rather than "technological" in order to ensure that business innovations may be included even when they appear to have no basis in new technology. However, we are focussing on industry and do not intend to cover "social" innovations such as changes in family patterns, work habits, and so on. We are excluding technically workable inventions which are not commercially successful (even if failure is due to management error, "acts of God" or the extreme nature of the technical advance). We also exclude non-commercial innovations such as those with primarily military or other uniquely government markets. By these standards, the portable micro-computer,

the aerosol hair spray and the Boeing 747 are industrial innovations; heart transplants, the atom bomb and the Concorde, while innovations in the usual sense of the term, are not.

The activity of industrial innovation consists of the transformation of an idea into the new or improved saleable product or operational process. It includes all those scientific, technical, commercial and financial steps necessary for the successful development and marketing of new or improved products, processes and equipment.

Industry
A group of operating units engaged in the same or a similar kind of economic activity. (10)

Invention
A prescription for a producible product or operable process so new as not to have been "obvious to one skilled in the art" at the time the idea was put forward. (11)

R&D
Research and experimental development (R&D) comprise creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society and the use of this stock of knowledge to devise new applications. (12)

Technology
The pool of knowledge concerning the industrial arts. It consists of knowledge used by industry regarding the principles of physical and social phenomena, knowledge regarding the application of these principles to production, and knowledge regarding the day-to-day operations of production. (13)

Summary

In this chapter an attempt has been made to put some flesh on the bones of the definition of innovation. It was noted that innovations can normally be classified as either process or product, an important classification for understanding the phenomenon. Examples were given of some innovations and some of their effects. The role that some economists assign to innovation in economic growth was noted. Finally, several definitions were suggested for terms used in the paper.

Footnotes

(1) **Science Indicators: Improvements Needed in Design, Construction, and Interpretation**, Report by the Comptroller General of the United States, Washington, D.C., 1979.

(2) **Science Indicators - 1982**, National Science Board, Washington, D.C., 1983, p. ix.

(3) Canadian innovations are taken from **Ideas in Exile**, J.J. Brown, McClelland and Stewart Limited, Toronto, 1967 and **The Canadian Inventions Book**, Janis Nostbakken and Jack Humphrey, Grey de Pencier Publications, Toronto, 1976.

(4) **Science, Technology, and Innovation**, Battelle Columbus Laboratories, National Science Foundation, Washington, D.C., 1973.

(5) J. Enos, **Petroleum Progress and Profits: a History of Process Innovation**, MIT Press, 1962.

(6) Christopher Freeman, **The Economics of Industrial Innovation**, Frances Pinter (Publishers) Limited, London, 1982, p. 27.

(7) J.A. Schumpeter, **Business Cycles: a Theoretical, Historical and Statistical Analysis of the Capitalist Process**, McGraw-Hill, New York, 1939.

(8) David Dickson, "Technology and Cycles of Boom and Bust", **Science**, 25 February 1983, pp 933-936.

(9) Freeman, **op.cit.**, p. 220.

(10) **Standard Industrial Classification Manual**, Dominion Bureau of Statistics, Catalogue Number 12-501, Ottawa, 1970.

(11) Jacob Schmookler, **Invention and Economic Growth**, Harvard University Press, Cambridge, Massachusetts, 1966.

(12) **The Measurement of Scientific and Technical Activities**, OECD, Paris, 1981, ("Frascati Manual" 1980).

(13) Edwin Mansfield, **The Economics of Technological Change**, W.W. Norton & Company, Inc., New York, 1968.

Innovation and Policy

Introduction

In this chapter we examine innovation from the point of view of those concerned with policy: policy for science and technology or the S&T aspects of industrial, economic and social policy. "The Effects of Innovation" attempts to demonstrate why such persons should be interested in innovation. The second section, "The Climate for Innovation", describes factors which affect the extent and types of innovation. In order to develop an effective policy, one must identify the most appropriate factor upon which to operate. We suggest that it is convenient to consider them in three groups: those which are part of the S&T base available to innovators, those which are general incentives to innovate, and those which are part of the individual firm's capabilities. In the final section, "The Current Activity in Innovation", we try to identify the phases of the innovation process. Such a classification can be useful for policy purposes if one wishes to concentrate programs on a phase or activity, such as R&D.

The Effects of Innovation

First let us look at the effects on the innovator. These will depend on the type of innovation and on the business of the innovator. A process innovation will improve the productivity of the innovator's operations. Products will become cheaper or better or both (or the product price and quality could remain the same and the costs could decrease). The most common effect would be an increase in sales (quantity and revenue) and profits, although in close competition innovation could be needed just to survive and to maintain market share. At the firm level, therefore, one can usually

expect changes in the levels and proportions of resources used and increases in sales and profits.

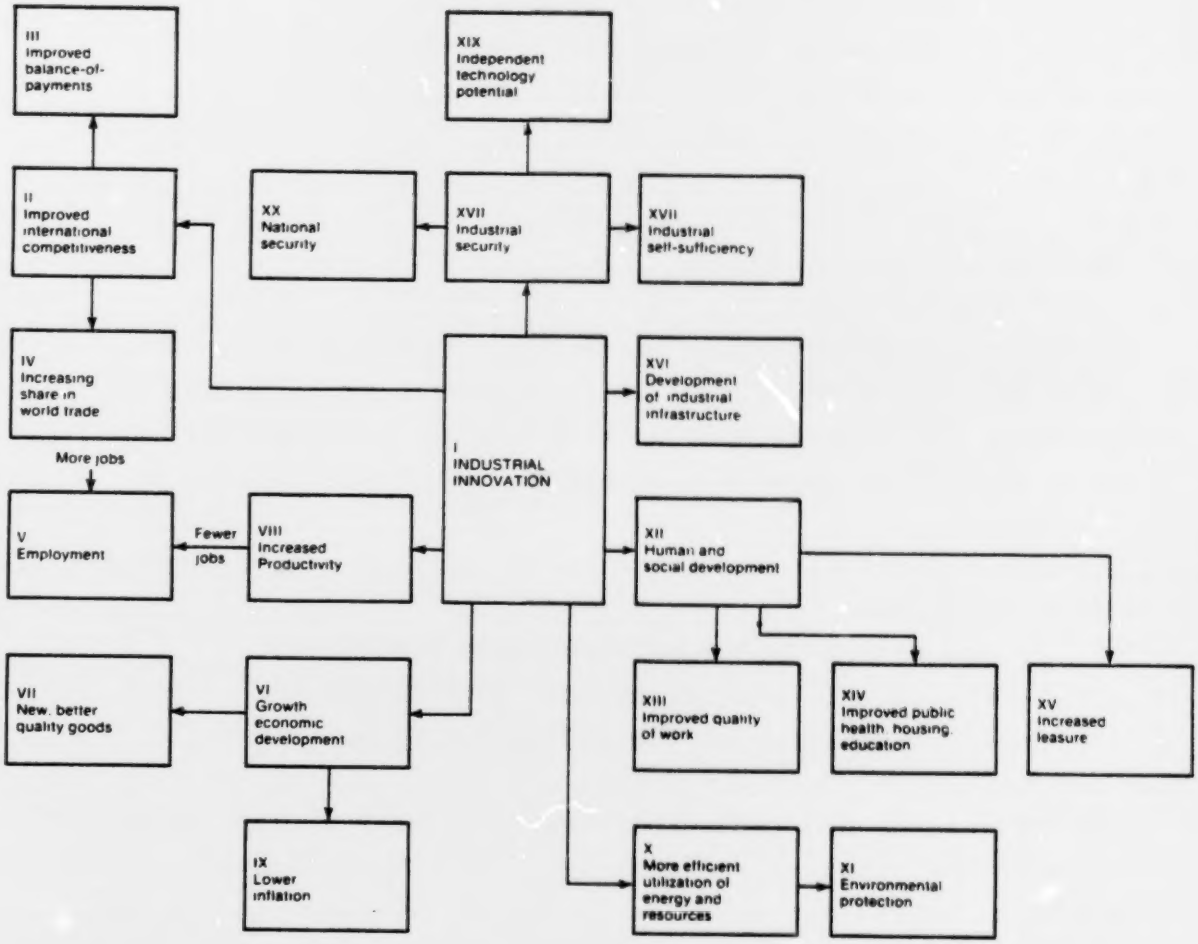
As a result of the process innovation, the firm's product, and those of its innovating competitors, may become so cheap or so improved that it will increase the productivity of its customer firms (e.g., cheaper gasoline and motor vehicle transportation and manufacturing). It could even create new industries (e.g., cheaper aluminum and canoes, mobile homes).

Other firms in the industry will attempt to improve their competitive positions by developing or acquiring similar innovations (the process of technological diffusion), by improving their productivity in some other way or by seeking to retain market share through non-technological factors (e.g., packaging, service, advertising, legislation). When a major process innovation or cluster of innovations has become standard technology for an industry, it may be a rather different industry than before - the effect of the assembly line on the manufacture of motor vehicles is an obvious example.

A product innovation should affect the innovating firm in the same areas: changes in production inputs, increases in sales and profits. A major innovation or group of innovations, as for processes, can result in new industries. In fact, as noted earlier, industries are created because of innovations: cannon making, textile machinery, automobiles, TV sets. Some products, such as pharmaceuticals, toys and torpedoes, are of interest mainly to consumer or other non-industrial markets. Although such products may affect other industries as well (e.g., toys and plastics, synthetic materials, and microelectronics), product innovations which are used by other industries are of particular interest. Besides the effect on the innovating industry, there will be changes in the productivity of the operations of the customer industries (and of the customers' customers). The example of

the creation of a loaf of bread has been used to illustrate the concept of the Gross National Product. Let us return to that loaf. As a result of research into improving wheat strains, innovations are possible in the seed grain. Innovations in farm machinery can decrease the effort per unit required to plant and harvest the crop. Innovations in fertilizers, herbicides and insecticides can improve the yield, at least in the short-term. Innovations in railroad stock and grain handling machinery will lead to cheaper and more efficient transportation of grain. Improvements in milling machinery can mean cheaper flour; innovations in mixing machinery and ovens permit larger scale production of bread; innovations in packaging lead to changes in storage and distribution of loaves. Clearly, innovation in the baking industry can be only part of the story of innovations and bread.

Innovations, as an extremely important factor in productivity change, in industrial change and in international competition, must interest anyone interested in economic policy, particularly those interested in the role of technology and economic growth. This reasoning can be crudely summed up as - "innovation good, more innovation, better" - and forms the justification for policies designed to encourage innovation. There are, however, other reasons for being interested in innovation. As noted earlier, industrial innovations have social as well as economic effects. Labour saving process innovations, such as the catalytic cracking process, and product innovations, such as the combine, are obvious examples of innovations with social effects. Others may, or may not, be ultimately labour saving but certainly have social effects (e.g., home sewing machines, micro-computers and TV sets). In addition, industrial innovations can often have ecological effects, as witnessed by the current debate on the possibility of global warming, on the loss of farm soil and on acid rain. There are, therefore, several rather



Source R. Rothwell and W. Zegveld, Industrial Innovation and Public Policy, London, Frances Pinter, 1981

important reasons for being interested, at a policy level, in innovations. However, those interested in innovations because of their social and ecological effects probably require information on specific innovations rather than statistics. Science and technology indicators serve the first set of interests (economic growth) better than the latter.

The Climate for Innovation

If it is assumed that innovation is, in the main, good for the country, then policy-makers will wish to encourage the creation and maintenance of a favourable environment. What is a favourable climate for innovation?

Factors affecting the climate for innovation can be arranged in three groups:

- the science and technology base available;
- the general incentives to innovate; and
- the capability of the individual firm.

By the science and technology base available to the innovator we mean the quantity and quality of persons, information and capital equipment which may be used. The most important component of the base is personnel - scientists, engineers, technologists and skilled workers. Another component is the dissemination system for printed or machine-readable scientific and technological information. A third element is the stock of capital equipment. It is, therefore, reasonable to expect policies which favour:

- school education in the sciences;
- training in technology and the skilled trades;
- university education in engineering and the sciences;
- widespread employment of S&T personnel;
- mobility of S&T personnel;

- numerous and well-stocked S&T libraries;
- effective and popular S&T information networks; and
- up-to-date capital equipment and machinery.

This group might be said to cover "technology push" factors. A strong S&T base will help the innovators to be closer to the leading edge and help to minimize the effort required to overcome an innovation's scientific and technical problems. They will also be better able to perceive the technological opportunities of the moment.

The second group covers the general incentives to innovate. These are, perhaps, less obvious than the elements of the science and technology base. One would be a cultural atmosphere which favours innovation, i.e., a society which encourages or at least permits change in organizations, systems, products and procedures. Another would be the economic environment. Innovation is encouraged when the innovator can expect to be rewarded for success. However, the relationship between the economic climate and innovation is not clearcut. It seems logical to postulate that lean times would provide a particular incentive to implement innovations in processes, especially cost-saving innovations. On the other hand, the influence on product innovations could be varied. Innovation costs money; other things being equal, innovation will be favoured when risk money or venture capital is plentiful and cheap. It may be that good times favour the more expensive product innovations, especially of the firms who tend to be continuous innovators. In times of slimmer order books, less frequent innovators may be driven to innovation to survive, and one can argue that such innovations will tend to be less costly. For our purposes, however, the nature of the relationship, if one exists, is not that important, since no policy maker would favour a poor economic situation even if it were to benefit innovation.

The capabilities of individual firms are the final determinants of innovation or at least of who will be the innovator. As a result of research carried out at the Science Policy Research Unit in the late 1960s and early 1970s, Freeman suggested several characteristics of successful innovating firms:

1. Strong in-house professional R&D.
2. The use of patents to gain protection and to bargain with competitors.
3. Careful attention to the potential market and substantial efforts to involve, educate and assist users.
4. Entrepreneurship strong enough to effectively coordinate R&D, production and marketing.
5. Good communications with the outside scientific world as well as with customers. (1)

These characteristics might be generalized as follows:

- numerous and effective industrial R&D units;
- effective patent system;
- effective marketing;
- entrepreneurship; and
- effective science and technology information system.

Innovations, as mentioned earlier, are of many types. Most firms have the capability of undertaking minor innovations, few are capable of radical innovations. Freeman has characterized the degree of uncertainty associated with different types of innovations in the table below:

TABLE. Degree of uncertainty associated with various types of innovation

1	True uncertainty	fundamental research fundamental invention
2	Very high degree of uncert.	radical product innovations radical process innovations outside the firm
3	High degree of uncertainty	major product innovations radical process innovations in own establishment or system
4	Moderate uncertainty	new 'generations' of established products
5	Little uncertainty	licensed innovation imitation of product innovations modification of products and processes early adoption of established process
6	Very little uncertainty	new 'model' product differentiation agency for established product innovation late adoption of established process innovation in own establishment minor technical improvements

" ... The distinction between in-house process innovation and open market product innovation is very important here. Product innovation involves both technical and market uncertainty. Process innovation may involve only technical uncertainty if it is for in-house application, ..." (2)

Policy makers will be interested in reducing the amount of uncertainty associated with innovation in order to permit firms to use their capabilities to the fullest. To do so, they would work through programs to improve the S&T base and the general climate for innovation as well as those affecting firm capabilities directly.

The Current Activity in Innovation

Originally innovation was a small-scale activity, carried out mainly by inventor-entrepreneurs. Of course, the individual entrepreneur was also the dominant form of economic organization until the last half of the 19th century. Today, while innovators such as Bombardier, Lear and Land can still develop innovations which may lead to the formation of new firms and industries, the corporation is the dominant form of economic organization. This is reflected in the sources of innovation. For example, in 1921-1925, almost 71% of U.S. patents were awarded to individuals. In 1956-1960, the share of individuals had dropped to 36%. (3)

We are justified, therefore, in looking at the activity of innovation within the corporation. Furthermore, although many innovations take place as a result of a series of incremental improvements "on the shop floor", or even as an accident, we shall concentrate on innovation as a planned and organized corporate activity. Not only is it probable that the larger innovations are derived from this type of operation, it may be the only one which can really be affected by science and technology policy measures. Two example outlines are given in the Appendix of the corporate organization of innovation.

An extremely simplified model of innovation in its most complete form is the following:

- scientific research
- experimental development
- product/design engineering
- tooling and industrial engineering
- manufacturing start-up

For product innovations, at some stage a set of activities

which may be labelled "new product marketing" is necessary, and possibly activities required for patenting. The examples in the Appendix give a better idea of the complexity of the full process, even though they are also simplified. An innovation need not, of course, pass through all these stages. Inventions may be made without R&D, or at least without any R&D by the innovating firm. Furthermore, a firm may acquire inventions from outside and become an innovator by successfully commercializing them. It may also become an imitating innovator by adapting or copying the innovation of another; it can buy the innovation (rights, know-how, possibly machinery and materials) from the original innovator or otherwise acquire it from an affiliated company. Freeman has a table which illustrates the emphasis on the various activities placed by different types of firms. (4)

TABLE. Science and Technology Activities and Firm Strategies

S&T activity	Strategies of the firm					
	Offen-sive	Defen-sive	Imita-tive	Depend-ent	Tradi-tional	Oppor-tunist
Fundamental research	4	2	1	1	1	1
Applied research	5	3	2	1	1	1
Experimental develop.	5	5	3	2	1	1
Design engineer.	5	5	4	3	1	1
Prod engr./ qual. cont.	4	4	5	5	5	1
Technical services	5	3	2	1	1	1
Patents	5	4	2	1	1	1
S&T info	4	5	5	3	1	5
Education & trg	5	4	3	3	1	1
LR forecast. & product planning	5	4	3	2	1	5

5 = most effort, 1 = least effort.

The significance, to the policy-maker, of the phases of the innovation activity is that he may wish to intervene in selected phases in an attempt to improve the climate for innovation. This is, in fact, the usual strategy. It underlies another comment by Freeman.

"Three sets of technology policies seem particularly relevant:

(i) Policies which aim directly at encouraging firms to take up radical inventions/innovations. ... Support for fundamental research, for 'enabling' or 'fundamental' technology and policies designed to improve the coupling system are all of critical importance.

(ii) However, the early stages of radical innovations do not have big economic effects. Only large-scale diffusion can

have such effects and therefore a second set of policies aimed at improving the diffusion of existing, but still relatively new and radical, innovations throughout the various sectors is essential. ... There is scope for a variety of strategies tailored to national circumstances but there can be little doubt that a policy of 'intangible investment' in the expansion of education and training can be a useful aid to adaptation and a valuable 'counter-cyclical' investment strategy.

(iii) A third set of policies aims at improving the import and the internal diffusion of foreign technology. ... as Japanese post-war experience shows, a deliberate policy towards the import of foreign technology, coupled with autonomous efforts to improve it, can be highly successful. ..." (5)

Other policies, not usually associated with the encouragement of innovation, should be considered in a full review of the topic. These could include, for example, technical information services; promotion of good design; marketing assistance such as trade fairs; commercial and technical intelligence on foreign markets, products and innovations; and up-grading of the technical and marketing skills of employees.

Summary

The chapter attempts to show why persons interested in policies for science and technology, industrial development or economic growth should be interested in innovation. We suggest that this concern is justified because of the role of innovation in productivity growth, new industry creation and employment changes. The heart of the chapter is a discussion of the environment which policy makers could favour in order to encourage innovation. Finally, the activities relevant to corporate innovation are reviewed from the point of view of possible government intervention to influence the total activity of innovation.

Footnotes

(1) Christoper Freeman, The Economics of Industrial Innovation, Frances Pinter (Publishers) Limited, London, 1982, pp 112 and 126 ff.

(2) Ibid., p. 150.

(3) Jacob Schmookler, Invention and Economic Growth, Harvard University Press, Cambridge, Massachusetts, 1966, p. 26.

(4) Freeman, op. cit., p. 171.

(5) Ibid., pp 220-222.

Innovation and Statistics

Introduction

This chapter recommends statistical and other information which could serve as indicators of the various aspects of innovation identified earlier. It consists of three sections. The first, "The Climate for Innovation", introduces a number of series which seem relevant to identifying and mapping patterns and trends in innovation and factors which influence innovation. "Detecting and Counting Innovations" deals with examining innovations at the micro-level; a procedure which seems to be hovering on the brink of institutionalization. Finally, the topic of providing indicators for the effects of innovation is briefly considered. Readers are reminded that indicators seldom coincide precisely with the phenomenon under review; in almost all cases it is desirable to analyze the movement or behaviour of groups of related indicators.

The Climate for Innovation

It was suggested in the previous chapter that the climate for innovation could be described under three headings. These same headings will be used to group the indicators which seem as though they should be part of the data base available to S&T policy analysts and advisors. The series listed below may, or may not, exist. Some, in fact, may turn out to be either unrealistic or irrelevant. All are suggested here as worthy of consideration.

1. The science and technology base.

a. School education in the sciences.

Without an adequate number of qualified school graduates, requirements for scientists and engineers cannot be met from national resources. Regular annual or biennial statistics on the following characteristics would seem to be relevant:

- number of high school graduates with some standard of hours of education in the sciences, by region;

- numbers of high school students in the senior grades who are receiving some standard of hours of science education, by region;

- numbers of secondary school science teachers, by qualification, age and region; and

- average scores in standardized science-oriented testing at school leaving or university entrance.

b. Training in technology and the skilled trades.

Modern industry and innovation require a wide range of personnel - from cleaners to financiers - but, in particular, good engineers, technologists and skilled workers such as machinists. Periodic statistics on persons trained in technology and the industrial skills could comprise:

- numbers of technologists and skilled workers, by specialty, age and region;

- numbers of students enrolled in technical trades courses and apprentice programs, by specialty and region; and

- numbers of teachers of technology, by qualification, specialization, age and region.

c. University education in engineering and the sciences.

Engineers can be involved in all phases of the innovation process; scientists tend to be more concentrated in research and teaching. Because of the length of time necessary to train scientists and engineers, good indicators of the current stock and new entries are crucial. The following statistics should be collected regularly (annually, biennially or triennially):

- numbers of university students studying science and engineering, by level of degree sought, specialization, citizenship status and region;

- numbers of graduates in science and engineering, by degree awarded, specialization, citizenship status and region; and

- numbers of teachers of science and engineering, by work status, qualification, specialization, age and region.

d. Employment and mobility of S&T personnel.

It seems logical to suggest that the greater the numbers of scientists, engineers and technologists, the more favourable the S&T climate for innovation. Not only are there more potential inventors, but their individual potentials are enhanced by the density of contact with their colleagues. Population censuses or similar surveys should be used to provide regular statistics on:

- numbers of employed scientists, engineers and technologists, by occupation, function, age, sex, industry and region;

- numbers of unemployed scientists, engineers and technologists, by specialization, age, sex and region; and

- work and career patterns of scientists, engineers and technologists for different occupations.

e. S&T information.

Science and technology, i.e., knowledge in the sciences and knowledge of technology, are constantly expanding. Teachers, students and personnel outside the university structure must keep up-to-date. This is particularly important when competing through innovation. Policy analysts and advisors should welcome periodical statistics on the S&T information system. These could comprise:

- S&T libraries or collections, by size of book and periodical holdings, specializations, age profile of holdings, staff, budgets, special facilities, organizational category and region;

- current S&T information resources of business establishments, by category (e.g., unit library, on-line to central S&T library, local research institute, local university, etc.), cost and associated staff; and

- S&T information networks, by organization, budget, staff, specialization, users and special facilities.

f. Capital equipment and machinery.

Capital equipment and machinery are embodied technology. Many innovations result from a series of marginal improvements; obviously a greater number of marginal improvements are needed to older machinery than to new to result in an improvement over the "state of the art" machines. Furthermore, those working with the most up-to-date equipment

will tend to be closer to the leading edge of a technology than those working with older equipment. The following kinds of statistics should be useful for policy analysis, although so far as we know, none of them are now collected:

- capital stock used, by industry, type of capital, normalized output capacity, average age, per-unit energy and labour requirements;

- latest capital equipment and machinery available to each industry, by industry, extent of use, operating cost per unit of output; and

- rate of diffusion of advanced manufacturing technologies, by technology (e.g., CAD/CAM) and by industry.

g. Expansion of the S&T information base.

A national base may be expanded by adding new information from other countries; the total base is expanded by research and experimental development. The international statistical series, Gross Domestic Expenditures on R&D (GERD), will serve as an indicator of this expansion. Policy analysts and advisors will also be interested in the sectoral structure of national GERDs.

2. General incentives to innovate.

It is difficult to suggest a set of statistical series which would help the policy analysts and advisors to assess the cultural and economic environment for innovation. Nevertheless, one could consider reviewing certain information, if collected on a systematic and regular basis. Examples of such information are given below. As for most statistics in this area, their value is greatly enhanced if comparable information is available for other countries which are relevant

to the first country because of similar size, institutions and economic problems.

a. Government incentives for innovation.

These should be grouped into whatever classifications seem useful, such as: financial and non-financial (e.g., free use of government facilities or information services); type of financial assistance (e.g., grant, contract, performance bonus, tax incentive, loan guarantee, reduced interest rate); innovation phase involved (e.g., R&D, product design, equipment modernization); industries involved (using the national standard industrial classification); and technologies or subject matter areas targeted (e.g., assistance program for microelectronics or for food processing). All incentives should be costed, using whatever estimates are necessary, to permit financial comparisons. Ideally, the continuing analysis of program or incentive benefits should be incorporated in the evaluation framework of each program; information needed for such analyses can also serve for indicators.

b. Apparent economic climate for innovation.

Statistics on the following items might be useful:

- effective rate of taxation of individual and small business incomes;
- new company listings on stock exchanges;
- share price index for companies in selected industries (e.g., communications, computers and computer services, biotechnology, scientific and professional instruments, drugs and some other chemical industries);(1)

- amount of "venture" capital available and amount committed or loaned out;

- average rate of interest paid by small business borrowers;

- absolute and relative number of company "births" and "deaths"; and

- rate of unemployment of persons who are looking for work in selected occupations such as physical and life scientists, engineers and technologists.

c. Apparent cultural environment for innovation.

It is suggested that a regular survey be carried out to assess people's attitudes to the sciences and technology, to innovation and change. Statistics collected for analysing the science and technology base could be used to provide an indication of the degree of "literacy" in S&T of the general population.

3. The capability of the individual firm.

It was suggested in an earlier section that innovation depended largely on R&D, use of the patent system, marketing, entrepreneurship and S&T communications. Practicable indicators for marketing and entrepreneurship have not been suggested, but something can be proposed for the other factors.

a. R&D activities of the firm.

- annual expenditures on R&D (normalized by sales or employment), by type of expenditure; and

- numbers of personnel engaged in R&D (normalized), by category.

These are among the best known statistics which can be used for innovation studies. However, they must be used in context, as indicated by two quotations from recent OECD studies. The first shows how R&D expenditure data for firms in the pharmaceutical industry must be qualified:

" ... the progress of knowledge has made it possible to predict the physiological effects of compounds with much greater ease. This reduces the time and money required to develop a new product. The costs of innovation have undoubtedly risen, but had it not been for the advancement of basic science they would have done so to an even greater extent. ...

... two separate indicators of R&D expenditures are required for assessing national scientific and technological capacities: R&D outlays by firms ... and R&D funding for health by governments and universities ...

As far as international competitiveness is concerned, the most significant indicators are the level and more particularly still the rate of growth of R&D by firms. The lead times required for innovation in pharmaceuticals mean that today's R&D expenditure is an indicator of relative competitiveness five to ten years from now." (2)

The second quotation refers to the role of R&D in the machine tool industry. In contrast to the pharmaceutical industry, R&D expenditures are a less useful indicator:

"Average R&D intensity has traditionally been fairly low in the machine tool industry and still remains so to a large extent. ... R&D expenditures have always represented only a part of the total outlays made for technology in the machine tool industry. The advent of electronic and in particular microprocessor technology has accentuated this situation. ...

The work of the machine tool industry consists of designing and producing machines which have to meet extremely diverse needs. It requires imagination and creativity and at the same time constantly developing technical knowledge. The inputs to a machine tool today include not only the industrial know-how of the tradesman, technician and engineer in the 'traditional' fields of mechanical and electrical engineering

- which still remain essential - but also the most up-to-date scientific and technological advances in microelectronics, computer techniques and in laser technology. All the industrial world's technological skill enters into the design and manufacture of a modern machine tool." (3)

b. Use of the patent system.

Because of the well-known variation in the propensity to patent, among firms and between industries, we must observe the data for this feature quite closely to determine how to qualify apparent movements and patterns. The following series could be considered:

- patents granted to companies over a period, normalized by R&D expenditures or scientists and engineers;

- an evaluation of patents granted, if possible (e.g. through citations in patent abstracts); and

- patents granted to companies compared to the totals in selected fields of technology.

c. S&T communications.

Firms could be asked to identify their sources of S&T information, with indications of the extent of the use and the cost involved. This should be part of the study of the S&T information base in the country. The Irish study of 1971 is worth noting. (4)

Detecting and Counting Innovations

It is desirable to be able to work with data on individual innovations for at least two reasons. One is that it enables us to give at least illustrations and examples which will give some reality to our theoretical arguments. The other is to permit us to seek for patterns and trends in the activity

of innovation, its causes and effects.

Recall the summary definition of innovation: "an industrial innovation is a new or significantly improved saleable product or an operational process in industry and commerce. It is something which did not exist before in its present form and it is something which works or which is a commercial success." It is apparent that, in order for us to detect innovations, they must be identified and described in such a way that we can screen them for novelty and commercial success. This means that large innovations will have a better chance of being detected than small ones; that consumer products will have a higher probability of detection than manufacturing processes; that older innovations will be favoured over newer ones. Biases are, therefore, almost inevitable in any project of innovation measurement.

A simple count of innovations is almost meaningless because of the unknown number of omissions. Working with individual innovations makes sense only if they are connected with their individual but comparable characteristics such as source of idea, nature of invention, costs, mix of activities, patents, sales, etc. By the collection and analysis of this type of information, groups such as the Science Policy Research Unit and individuals such as Edwin Mansfield have been able to make real contributions to our understanding of innovation as an activity and as a factor in economic growth.

How would a statistical agency go about surveying innovations? Statistics Canada carried out three pilot surveys of innovation in the early 1970's. These concentrated on the costs of innovation in relation to R&D and used R&D-performing firms as the sample universe. Firms were asked to identify costs of various phases of the innovation "process", either for a given year (the first survey) or for self selected innovations (the latter surveys). (5)

A somewhat similar approach was used by the Economic Council of Canada in 1979. All firms in five industries were sent a questionnaire covering a wide range of elements in the innovation process. "Firms were asked to identify and describe major innovations ... which they had introduced over the 1960-1978 period. Major innovations were defined as major new or improved products or production processes which contributed most to the firm's profitability ..." (6)

In the last two Statistics Canada surveys, information was received on 83 and 96 innovations; the Economic Council survey collected usable information on 283 innovations. In all these surveys, respondents were asked to identify the innovations for which they were prepared to supply estimates. Another approach, used by the Science Policy Research Unit in the U.K. and by Chris De Bresson in Canada, is to ask experts to identify significant innovations in different industries, their approximate times of appearance and the innovating firms. The identified firms would then be approached for information on specified innovations. This procedure probably yields a more representative set of important innovations but only later will it be known whether the innovators can provide the desired information.

There are now organizations attempting to keep track of new innovations as information on them appears in monitored newspapers or journals.(7) At least one European agency is attempting to collect periodic standardized information on innovations from innovating firms. It may be time now to consider a continuous attempt to identify innovations as they appear and develop a systematic collection of time-series data on them.

The Effects of Innovation

One can attempt to forecast the effects of current or emerging innovations, and one can attempt to identify the effects of current and past innovations. Both tasks are difficult, particularly the first, and the statistician can be concerned only with the second, in the hope of amassing information which can aid those interested in technology assessment and forecast or in integrating technological change into economic theory.

What are the effects of innovation? The innovator hopes for profit: profit from sales of the new product or from more sales of the cheaper/improved product. Unfortunately, sales and profits are dependent on other factors as well, from general economic conditions, to "Acts of God", to the quality of entrepreneurship. There is also the problem of time: in the short-run, the non-innovating firm may have higher profits precisely because of lower innovation activity. There may be a statistical co-relation between profits and innovation but, at our present level of industrial statistics and conceptual development, it is best to keep a very open mind.

"While it is generally presumed that technological change leads to economic growth and productivity increases, it is also widely acknowledged that the quantitative impact of such change is difficult to appraise ....

It is probably safe to say that growth, sales, exports and high rates of return are frequently associated with high levels of research expenditures, but that a clear causal flow from research to economic performance is quite difficult to establish. ..."(8)

However, the rate of change in an industry's sales may be a fruitful indicator. An increase in sales is due to increased demand. Why has the demand increased? Perhaps because of decreased competition due to natural disaster, war or other political intervention. If not, look for innovations: innovations which use the industry's product, innovations in the industry's product and/or innovations in the materials or processes used by the industry. An unusual rate of increase in sales may well indicate the presence of an unusual amount of innovation.

Ultimately, innovations are generally expected to result in increased welfare. However, there is no real consensus on the concept of welfare nor on its measurement. "In measuring aggregate output and its growth - a task that has as its ultimate purpose the quantification of changes in economic welfare - it is nearly impossible to capture such consequences of change in technology as a richer choice of products and services or an improved quality of goods."(9) There are cases, in the fields of agriculture and health, where fairly direct paths have been traced between specific innovations, or cluster of innovations, and clear increases in welfare.

From the point of view of present policy formulation, it appears to us that the measurement of the effects of innovation is peripheral to innovation indicators. Not only are the uses of such historical estimates unclear, the collection of a comprehensive set of data for estimating would be a massive and costly effort. Certainly studies should be supported, as in any other field of economic research, but they cannot yet be incorporated into the program of innovation indicators.

Summary

A number of specific measures have been suggested which might serve as indicators for innovation in a policy-making context. These measures, some now available and some only ideas, have been considered under three headings. Those in the first, "The Climate for Innovation", are both more immediately useful for planning and more developed than those in the two other groups. In fact, it is recommended that the statistical services have little to offer at this time in the collection or analysis of data for indicating the effects of innovation ("The Effects of Innovation"). However, it may now be time for a serious consideration of systematic data collection on individual innovations to provide information for future analyses ("Detecting and Counting Innovations").

Footnotes

(1) For example, the Toronto Stock Exchange is reported to be prepared to publish a "high-tech" stock index based on three industries: computers, electronics and communications. Globe and Mail, 18 May 1984.

(2) "Trade in High Technology Products - An Examination of Trade Related Issues in the Pharmaceutical Industry", DSTI/SPR/83.101, OECD, Paris, 7 November 1983, pp 24 and 26.

(3) "Trade in High Technology Products: An Examination of Trade Related Issues in the Machine Tool Industry", DSTI/SPR/83.102, OECD, Paris, 9 November 1983, pp. 17-18.

(4) A Survey of Scientific and Technical Information in Ireland, Institute for Industrial Research and Standards, Dublin, 1973.

(5) "Science Indicators: The Measurement of Technological Innovation", DSTI/SPR/76.44/04, OECD, Paris, 22 October 1976, Selected Statistics on Technological Innovation in Industry, Catalogue 13-555, Statistics Canada, 1975 and "The Costs of Technological Innovation", H. Stead, Research Policy, No. 5, 1976.

(6) "Preliminary Report: Innovation and Technological Change in Five Canadian Industries", Discussion Paper No. 176, Dennis DeMelto, Kathryn McMullen and Russel Wills, Economic Council of Canada, 1980, p. 270.

(7) For example, the New Technology Digest, prepared by the Financial Times Business Information Consultancy, identifies 400-500 innovations a month.

(8) Kristian Palda, Bohumir Pazderka, Approaches to an International Comparison of Canada's R&D Expenditures, Economic Council of Canada, Ottawa, 1982, pp. 2-3.

(9) Ibid., p. 2.

Conclusion

In this note we have tried to give a definition or describe a concept of innovation which would be useful to both the policy maker and the statistician. Although it may seem redundant to attempt to state why those involved in developing economic and industrial policies should be interested in innovation, we have done so, very crudely, by commenting on the effects of innovation. On the whole, innovation seems to lead to improvements in the quality of life. In any case, it is a fact of industrial life that technological change cannot be ignored since it affects the most important characteristics of almost all products: quality, cost, novelty, and reliability.

It is difficult for the statistician to offer much to the policy-maker or analyst on the effects of innovation. Innovations are difficult to consistently define and identify; their effects are even less identifiable and measureable, often taking decades to develop. History provides sufficient examples of the effects of past innovations for all to realize the importance of the topic; the effects of current and potential innovations are the domain of technological assessment and forecast. The statistician has, therefore, only an indirect role to play.

Innovations, like all products of human genius, cannot be produced on command. A policy designed to encourage innovation is one which attempts to develop a favourable climate for innovation. We have identified a number of factors which could be considered to affect the climate for innovation and grouped them into three classes:

- the available base of science and technology;
- general incentives for innovation, and
- the capability of the individual firm.

This is not only the most relevant area of interest for the policy-maker, it is also the one in which the statistican has the most to offer. We are able to suggest many indicators which should be helpful, some already part of the statistical program of many countries, others which need to be developed. In view of the importance of a dynamic, i.e., innovative, domestic industry, and of the amounts of money currently spent to encourage industrial innovation, the minor expenditures required to develop better planning information should be considered money very well spent.

Innovation is both an event and an activity. As an event, it appears as a commercially successful new or improved product or operational process; as an activity, it consists of the steps leading up to that event. Both aspects of innovation are of interest for government policy and programs and, therefore, for government statisticians. Because of their different effects, we would wish to be able to distinguish between product and process innovations. Because of the potential for different programs, it is important to be able to distinguish the phases of the innovation activity. At present, most of the attention has been directed to the R&D phase, which is the one with the greatest technical uncertainties.

APPENDIX

Two examples of the organization of innovation in large industrial corporations are given in this appendix.

A characteristic programme for product development

STAGE

1 Policy formulation

1. establish strategic objectives
2. lay down outline timetables, overall budgets and guide lines for innovation

2 Preliminary research

1. select an invention, discovery, scientific principle, product idea or technological base
2. identify an area of need, marketing opening, consumer appetite, product deficiency or value base
3. establish the existing state of the art (library and market research)
4. prepare outline performance specification (a verbal prescription for a proposed product - specification 1)
5. identify probable critical problem areas

3 Feasibility study

1. establish technical feasibility (basic calculations)
2. establish financial viability (economic analysis)
3. resolve critical problems in principle (inventions)
4. propose outline overall solution(s) (sketch designs 1)
5. estimate work content of phases 4 and 5 and probability of a successful outcome (risk analysis)

Out of 10 product ideas emerging from stage 3 ...

4 Design development

1. expand and quantify performance specifications (specification 2)
2. develop detailed design (design 2)
3. predict technical performance and product costs
4. prepare design documentation
5. design technical evaluation experiments and user trials

... perhaps 3 go to prototype stage ...

5 Prototype development

1. construct prototype(s), mock-ups (prototype 1)
2. conduct bench experiments with prototypes
3. evaluate technical performance
4. conduct user trials with prototypes (trials 1)
5. evaluate performance in use

6 Trading study

1. re-appraise market potential in light of trials
2. re-appraise costings
3. appraise marketing/production problem
4. revise basic objectives (strategic planning) and development budget
5. revise performance specification (specification 3)

... and one survives for production development.

7 Production development

1. develop a production design (design 3)
2. execute production design documentation
3. design technical, user and market trials
4. construct pre-production prototypes (prototype 2)
5. conduct technical, user and market field tests (trials 2)
6. appraise trials results and modify design

8 Production planning

1. prepare marketing plans
2. prepare production plans
3. design packaging, promotional material, instruction manuals
4. design jigs and tools

9 Tooling and market preparation

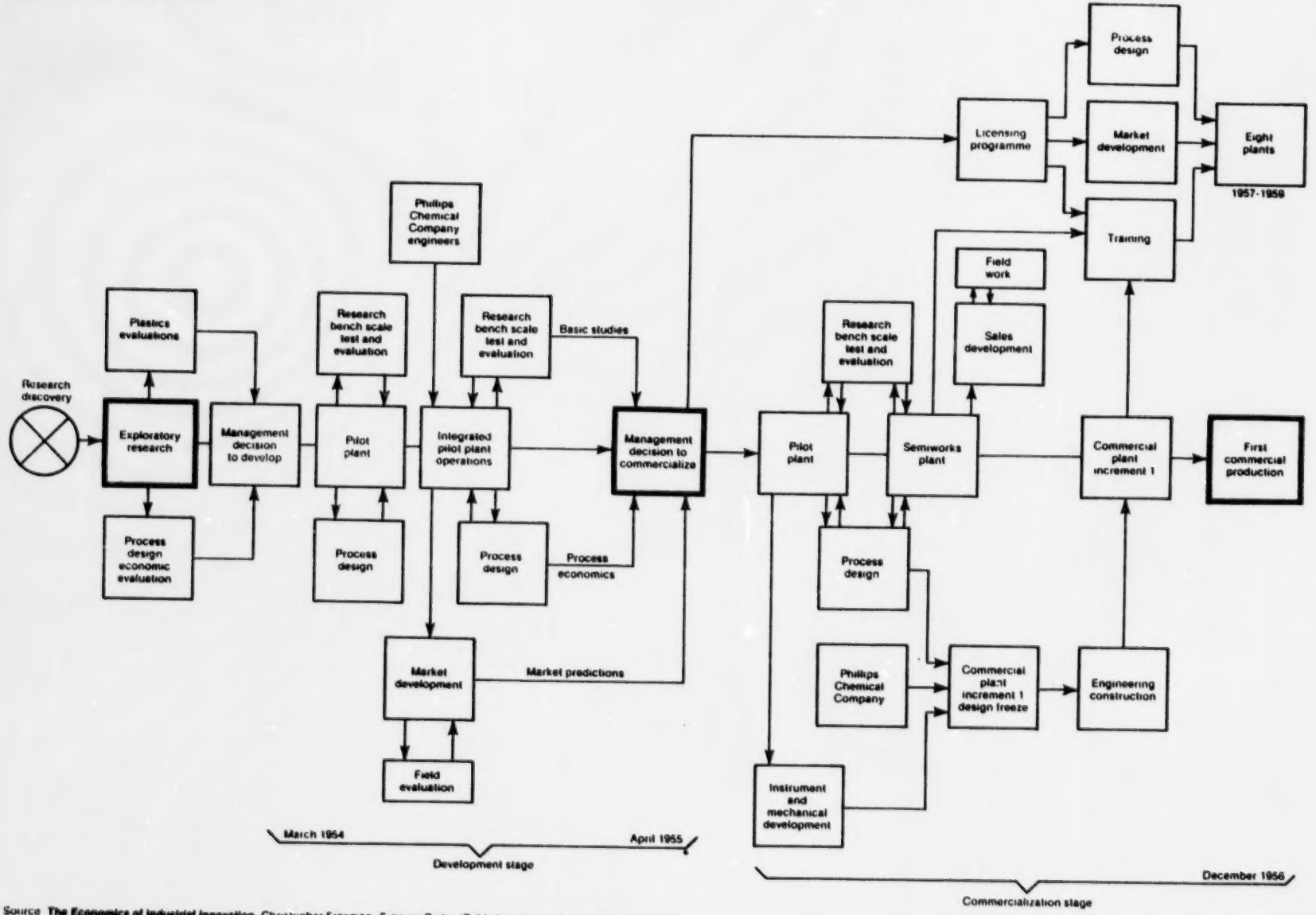
1. construct jigs and tools
2. construct trial batch of products off tools (prototype 3)
3. test trial batch (trials 3)
4. produce marketing materials and print
5. install marketing machinery
6. install production control machinery

10 Production and sale

1. initiate marketing effort
2. commence production and sale
3. collect market, user, repair and maintenance feedback
4. make recommendations for second generation designs (stages 2 to 4)
5. make recommendations for research (stages 1 and 2)

Source: **Techological Innovation - A Methodology**, L. Bruce Archer, Science Policy Foundation, London, England, 1971.

Phillips Petroleum Company



Source **The Economics of Industrial Innovation**. Christopher Freeman. Frances Pinter (Publishers) Limited. London. 1982. p. 66